GLASSES IN TUCSON (IRUNGR): A SIMS STUDY

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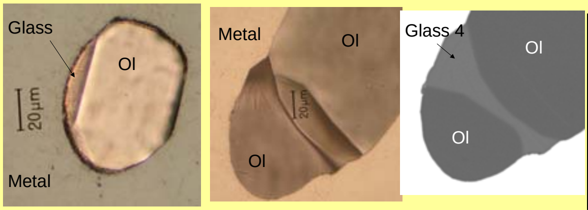
Introduction:

Tucson is a unique ataxite iron meteorite with about 8 vol% silicates [1]. The high Si (0.8 wt%) and the very low Ge content of the metal [2] make Tucson distinctive among the iron meteorites with silicate inclusions [3]. Silicate inclusions from Tucson, first reported by [4], have a remarkably reduced state [5]. Detailed chemical and mineralogical studies of these inclusions [1, 6] include a description of glasses that occur between crystalline phases. However, there has been no mention of the presence of primary glass inclusions in olivines. Here we report the first trace element study of glasses from glass inclusions in olivines and mesostasis glasses occurring between phases in the Tucson iron meteorite.

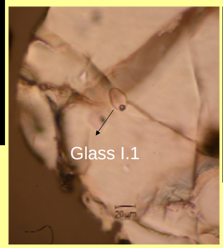
SEM picture of Tucson: thin section L3951 (length of the image: 2 cm)

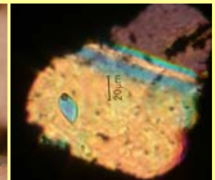


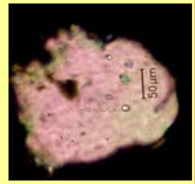
Transmitted light and SEM images of a typical silicate inclusion in Tucson with olivine having round surfaces against metal and crystal faces against glass.

Results

Studies were performed on the thin section L3951 from the NHM, Vienna. Here, silicate inclusions are small, mostly composed of olivines and olivine and glass. Olivine grains generally have round surfaces against metal and crystal faces against glass (Fig. 1), as has previously been reported [1]. The glass between olivines is clear without any signs of devitrification. Glass inclusions in olivine - with sizes varying between 5 and 35 µm - are also composed of clear glass and a shrinkage bubble. They have rounded or sub-rounded shapes and are mostly found in clusters, rarely as isolated inclusions.





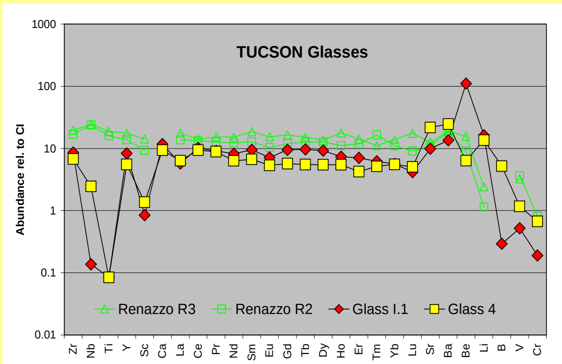


Primary glass inclusions in olivines: occuring isolated or forming clusters.

Both types of glasses (glass inclusions in olivine (Glass I.1) and mesostasis glass between olivines (Glass4, Table) have a Si-Al-Ca-rich composition, with the glass inclusion having a higher content of SiO2 (e.g., 57 wt%) and a lower content of Al2O3 (e.g., 21.4 wt%) compared to the glass between olivines (SiO2: 48.9 wt%, Al2O3: 28.1 wt%). Both types of glasses have similar CaO contents (~20 wt%), very low contents of FeO and are free of Na and K.

Table EMP analyses of glass and olivine in Tucson

	Glass I.1	Ol host	Glass4	Ol	Ol
SiO2	57.0	42.8	48.9	42.0	42.1
Al2O3	21.4		28.1		
FeO	0.19	0.19	0.81	0.23	0.42
MgO	1.58	57.2	3.17	56.7	56.9
CaO	19.6	0.16	19.6	0.11	0.12
	99.8	100.4	100.6	98.9	99.2



Trace element contents of both types of glasses are similar, with refractory elements having abundances around 10 x CI (Fig. 2). Exceptions are Nb (0.1 – 2.4 x CI), Ti (0.08 x CI) and Sc (0.8 - 1.3 x CI), which are depleted with respect to the other refractory trace elements. The REEs show an unfractionated pattern with abundances varying around 5 to 10 x CI . With respect to the moderately volatile and volatile elements, glasses show variable contents of Be, with inclusion glass (Glass I.1) having higher contents (100 x CI) than Glass4 (6.4 x CI). With respect to Sr, Ba and B, Glass 4 has higher contents of these elements (Sr, Ba: ~25 x CI, B: 6.4 x CI) than Glass I.1 (Sr, Ba: ~11 x CI, B: 0.3 x CI). Both glasses have relatively low contents of the moderately volatile elements Cr (0.2 – 0.7 x CI), as well as of V (0.5- 1.2 x CI).

Figure 2. CI-normalized trace element abundances in glasses of the Tucson meteorite. Glasses from Renazzo (in red) are plotted for comparison [10].

Discussion:

The Tucson section L3951 is a very antique glass-covered thin section. During the tasks of uncovering and re-polishing, part of the material was unfortunately lost. However, the very particular feature of the silicate inclusions is still visible, namely a parallel or sub-parallel curved aggregate arrangement, which in previous studies [6, 1] has been interpreted to indicate flow. The microstructure of the metal and its chemical homogeneity has led to the suggestion [7] that in Tucson the metal underwent rapid cooling (about 1ºC/1000 years). Because of the apparent flow structure shown by the silicates it has been suggested that the silicate mass was invaded by shock melted metal. Similarly, [1] proposed a turbulent impact mix of metal and a forsterite-enstatite silicate assemblage at high temperatures that resulted in volatilization of Ge and other volatile elements. Subsequent rapid cooling appears to be supported by the aluminous pyroxenes and the presence of glass in the silicate inclusions. Accordingly, the forsterite-enstatite silicate assemblage has been related to enstatite meteorites. However, a study of silicate components in Bencubbin, Kakangari, Renazzo, and Tucson has shown that the silicates share a similar petrology and that all are a highly reduced chondritic assemblage [8]. In addition, a comparison of glass compositions in the Tucson silicate inclusion and those in enstatite chondrites and achondrites clearly shows that they are compositionally not related.

Glasses in enstatite meteorites (chondrites and achondrites) are characterized by having high contents of SiO2 (70 - 80 wt%), very low contents of CaO (< 1.5 wt%) and being rich in alkalis (e.g., Na2O + K2O: 3.8 - 9.5 wt%) [9]. The Si-Al-Ca-rich Tucson glasses have approximately chondritic Ca/Al ratios and share this property with glasses in carbonaceous chondrite components (chondrules and aggregates). Tucson glasses plot inside the area (e.g., Ca vs Al) covered by the volatile-free glasses of the CR chondrites [10]. Surprisingly, a similar relationship is exhibited by oxygen isotopic ratios. The oxygen isotopic compositions of Tucson silicates – being remarkably similar to those in Renazzo and close to the line define by Bencubbin and Kakangari - led [8] to suggest a common origin for these unique meteorites in a region of the solar nebular undergoing evolutionary changes. Glasses can also be the result of nebular processes and - as proposed by the Primary Liquid Condensation (PLC) model [11] - they can represent samples of the first liquid (e.g., the glass precursor) to condense from the solar nebula. According this view, the Si-Al-Ca-rich composition of the glasses in Tucson as well as their elemental ratios (e.g., Ca/Al, Si/Al) is expected from the PLC model for a carbonaceous chondritic silicate assemblage. Similarly, the trace element contents of the glass inclusion and the glass mesostasis between olivines also match those observed in glasses hosted by olivines and mesostasis in components of carbonaceous chondrites [11-12].

Glasses in a single phase and those in between phases (after crystallization of olivine+enstatite+diopside) show similar trace-element abundance patterns that appear to be governed by cosmochemical fractionation, giving additional support to the PLC model. The depletions in Nb, Ti and Sc indicate condensation of the liquid from a vapor from which a highly refractory phase (perovskite?) has already been separated. Also, mainly due to the reduced nature of the silicate assemblage, a relationship with glasses of the IIE irons [13], which are enriched in Nb and Ti and could thus be counterparts of the Tucson glasses, cannot be ruled out.

The refractory and reduced silicates of the Tucson iron are embedded in a refractory and reduced metal, which has high and almost unfractionated refractory siderophile element abundances at ~3 – 9 x CI, low contents of volatile siderophile elements and high contents of Si and Cr [14]. An origin by condensation from the nebula can, therefore, not be ruled out [e.g., 15].

Conclusions:

Glasses in the Tucson iron meteorite provide a set of data that strengthens the PLC model and provides an additional step toward meteorite unification [16]. Beyond the element abundance data, the particular textures shown by silicate inclusions, in which olivines have crystal faces only in contact with the glass, might serve as a natural example for the proposed growing mechanism of crystals from a vapor with the help of a thin layer of surrounding liquid (Fig.1). All phases in Tucson, silicates and metal, appear to have a simple, one-step nebular origin after which they became isolated and protected from subsequent processing.

References: [1] Nehru C. E. et al. (1982) *Proc. Lunar Planet. Sci. Conf.* 13th, *J. Geophys. Res. 87*, Suppl., A365-A373. [2] Wai C. M. and Wasson J. (1969) *Geochim. Cosmochim. Acta 33*, 1465-1471. [3] Wasson, J. (1970) *Geochim. Cosmochim. Acta 34*, 957-964. [4] Smith J. L. (1855) *Am. J. Sci. 2nd series, 19, Nº 56*, 153-163. [5] Cohen E. (1905) *Meteoritenkunde*, Stuttgart, pp 88-100. [6] Bunch T. E. and Fuchs L. H. (1969) *Am. Mineral. 54*, 1509-1518. [7] Miyake G. T. and Goldstein J. (1974) *Geochim. Cosmochim. Acta 38*, 1201-1212. [8] Prinz M. et al. (1987) *LPS XVIII,* 800-801. [9] Varela M. E. et al. (1998) *Meteoritics & Planet. Sci. 33*, 1041-1051. [10] Varela M. E . et al. (2002) *Geochim. Cosmochim. Acta 66*, 1663-1679. [11] Varela M. E. et al. (2005) Icarus *178*, 553-569. [12] Varela M. E. et al. (2006) Icarus *184*, 344-364. [13] Kurat G. et al. (2007) *Meteoritics & Planet. Sci. 42*, 1441-1463. [14] Wänke et al. (1983) *Meteoritics 18*, 416. [15] Scott E. (1978) *Geochim. Cosmochim. Acta 42*, 1447-1458. [16] Kurat G. (1988) *Phil. Trans. R. Soc. Lond. A325*, 459-482.